TFAWS Active Thermal Paper Session

Development of a Pumped Two-Phase System for Spacecraft Thermal Control

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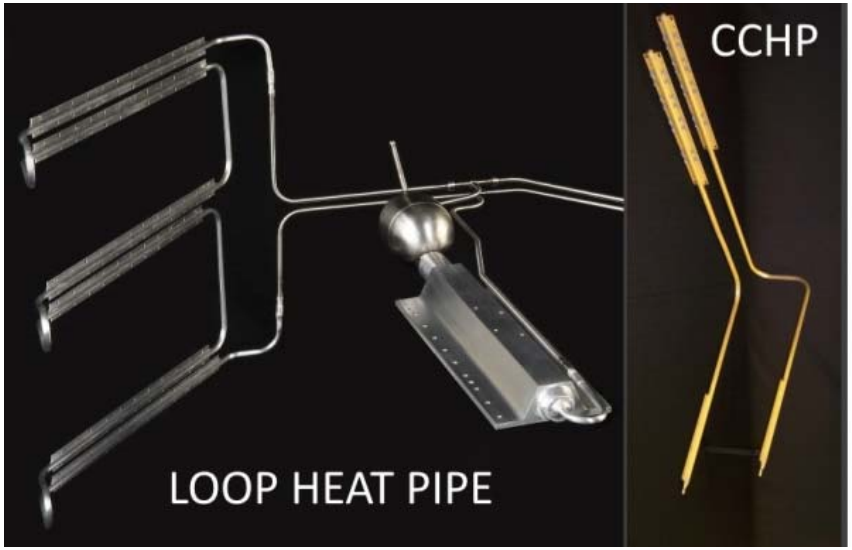
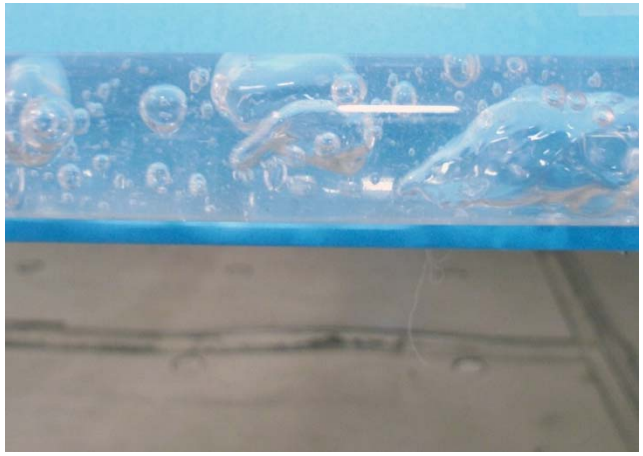
Background

- Conventional spacecraft thermal management
  - Capillary systems
    - Constant Conductance Heat Pipes (CCHP), Loop Heat Pipes (LHP), Capillary Pumped Loops (CPL)
  - Actively pumped single phase systems



Pumped Two-phase Benefits

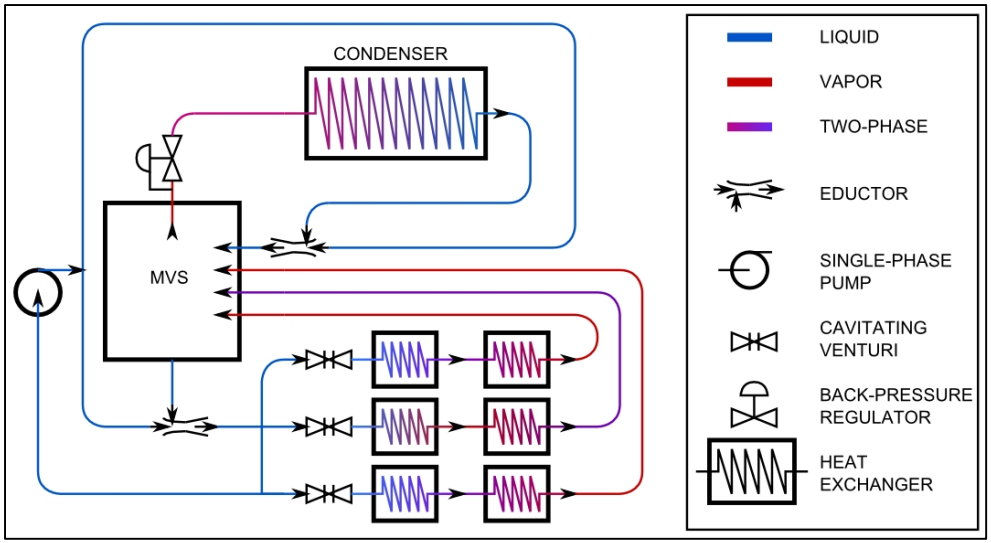
- Much higher heat capacity per unit mass
  - Latent heat of R134a is ~150X that of specific heat
  - Smaller flow rates = less system mass
- Isothermal heat transfer
  - Upstream heat loads won't affect coolant temperature available to downstream heat loads
  - Components can share thermal energy
- Enhanced heat transfer
  - Much higher heat transfer coefficients
  - Handles higher heat fluxes
  - Tighter packaging
- Tolerant of higher pressure drop
  - Much greater transport length than capillary two-phase systems
  - Enables the use of advanced heat exchangers with higher pressure drops



Two-phase flow during reduced gravity testing aboard the NASA C-9

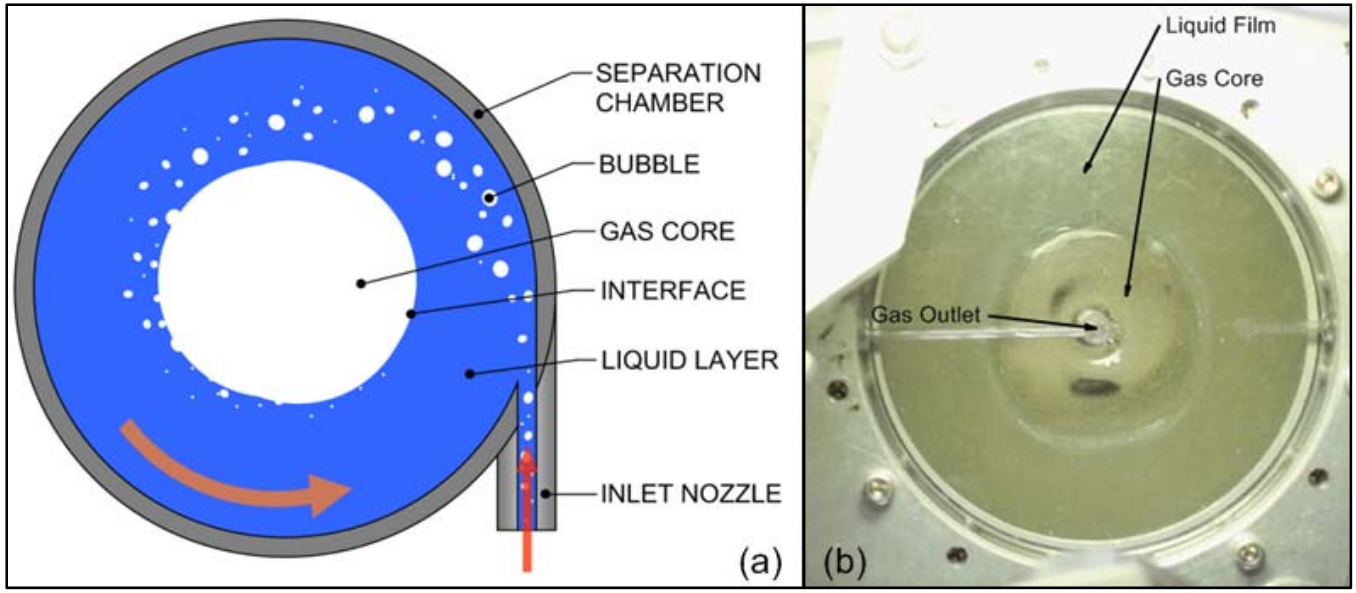
System Concept

- Separate single phase components from two-phase region
  - Single phase pump and eductors drive flow
- Integrate a Microgravity Vortex Separator (MVS)
  - Phase separation
  - Inventory control
- Manage an array of evaporators
  - In series and parallel



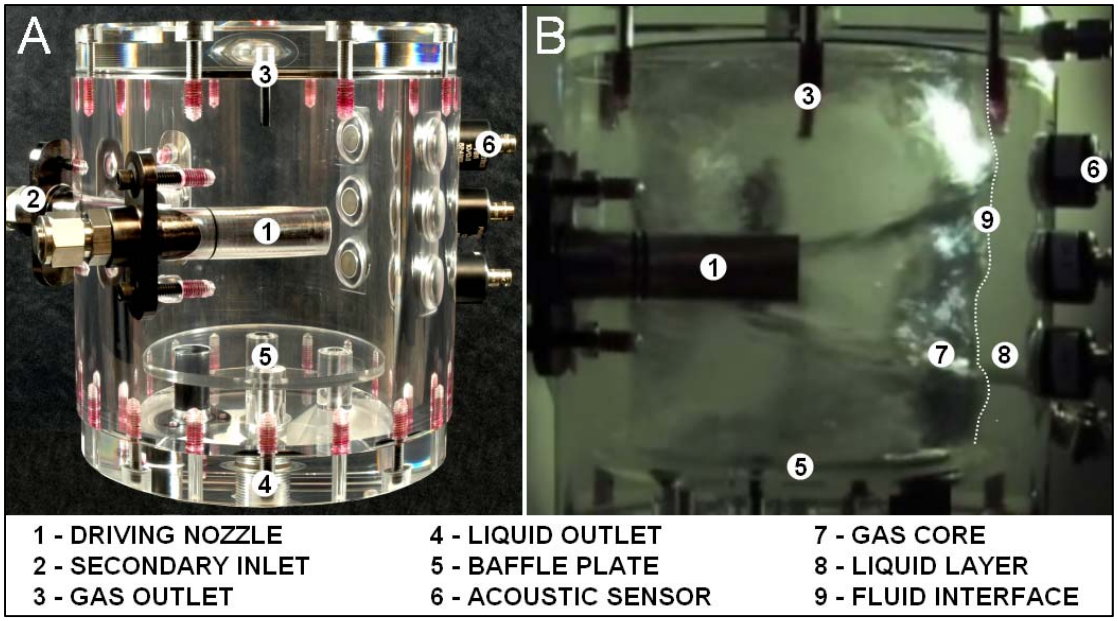
Microgravity Vortex Separator

- Centripetally accelerates flow to produce a forced vortex inside a fixed cylinder
- Vapor moving with the vortex experiences centrifugally-driven buoyancy
  - Liquid separates to the wall, vapor moves to the center



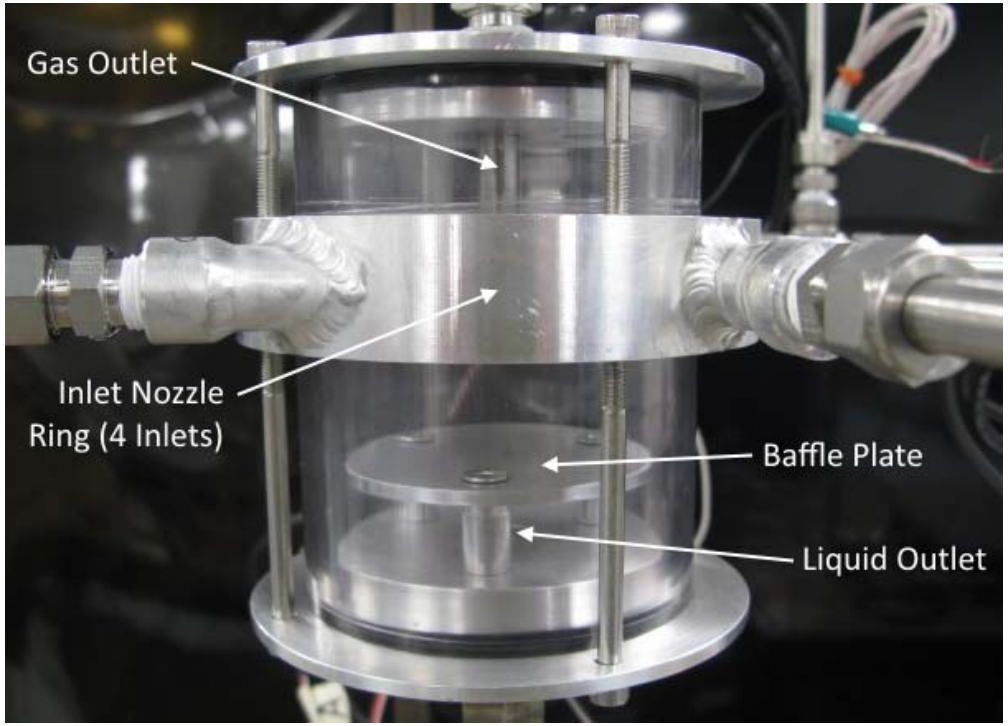
Microgravity Vortex Separator

- Liquid layer can be of varying thickness
  - Allows MVS to accumulate either fluid
  - Acoustic sensors can monitor liquid thickness to determine accumulated volume



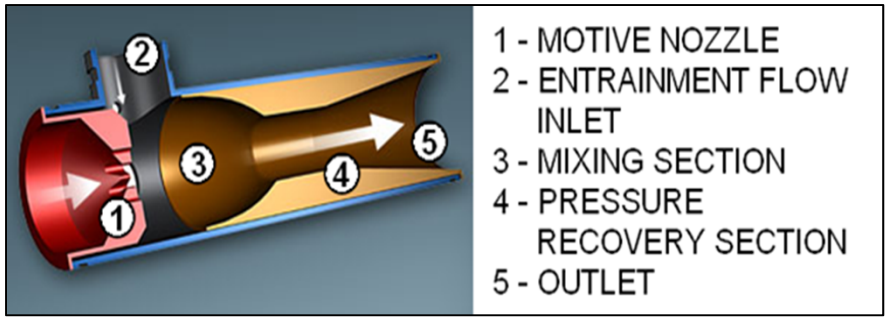
Fabricated MVS

- 3 in. diameter, 4 in. tall
- 4 inlets
  - 2 from evaporator legs
  - 1 from condenser
  - 1 auxiliary driving nozzle
- Aluminum and Polycarbonate
- Working fluid R134a



Eductor

- A Commercial-Off-The-Shelf eductor was used for the demonstration unit
- Venturi pump
  - Accelerates a motive fluid (liquid in this case)
  - Reduced pressure resulting from the high velocity of the motive fluid entrains the suction fluid (also a liquid)
  - The fluids mix and exchange kinetic energy
  - The mixture then expands before exiting the device, recovering pressure
- Passive and can pump both phases in the case of a separation failure
- The liquid outlet eductor provides NPSH for the liquid pump

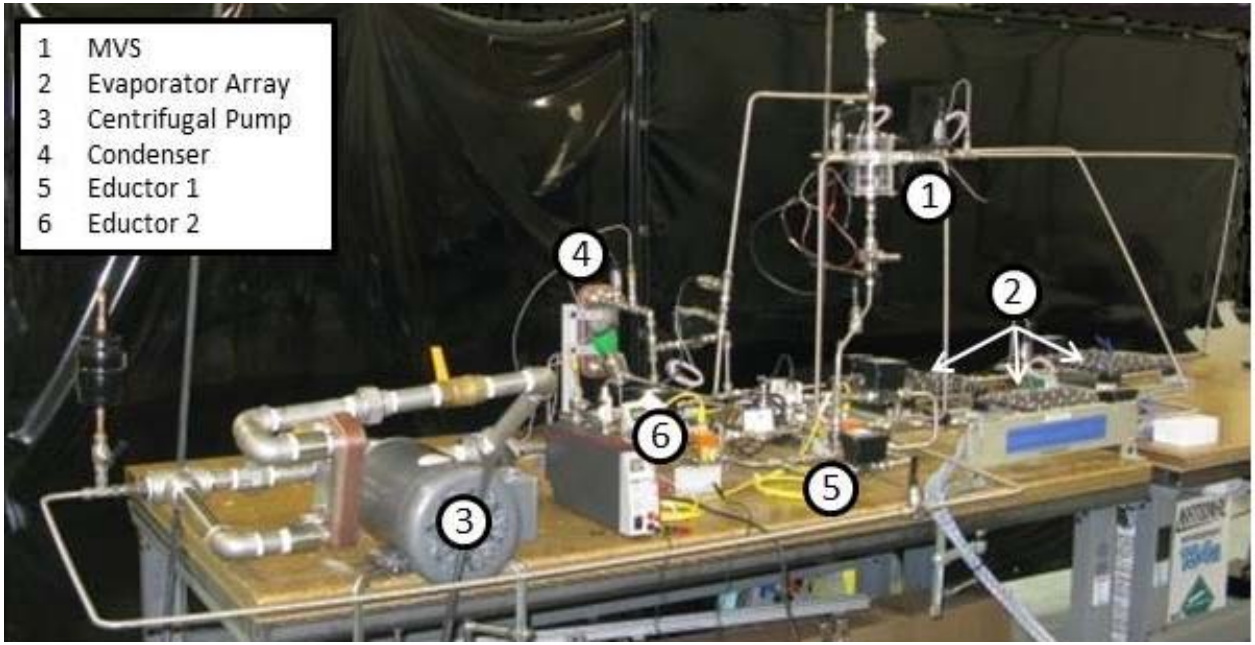


Evaporator Array

- Each cold plate has two parallel serpentine channels
- Two cold plates in series, one in series with these
- Aluminum heated surface with polycarbonate face for visualization

Experimental System

- Tested at constant flow rate for varying thermal loads
  - 130 W increments up to 1170 W for each cold plate
  - Cold plates tested separately, in series, and in parallel
  - Cold plates shut off and on to observe changes in other cold plates

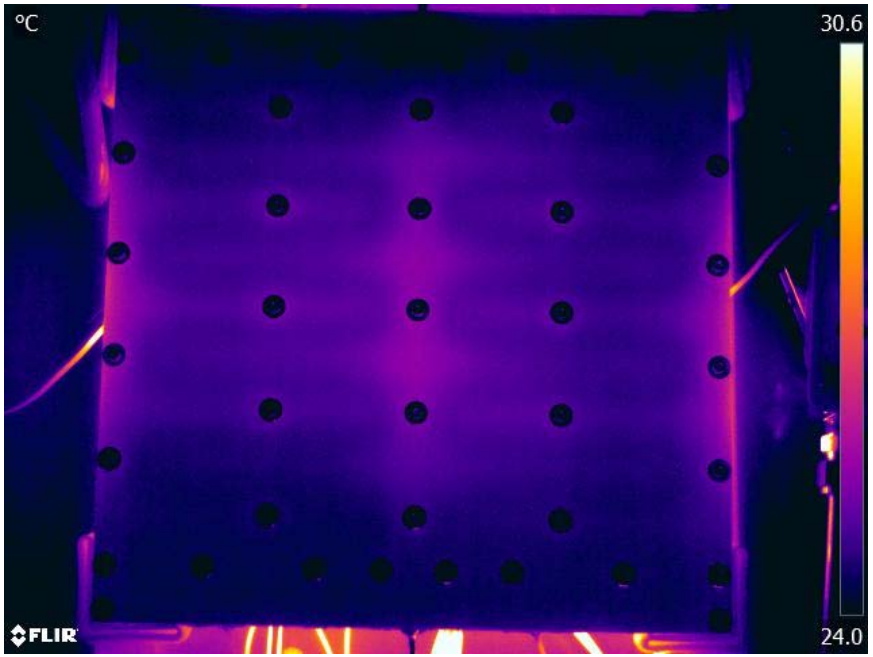


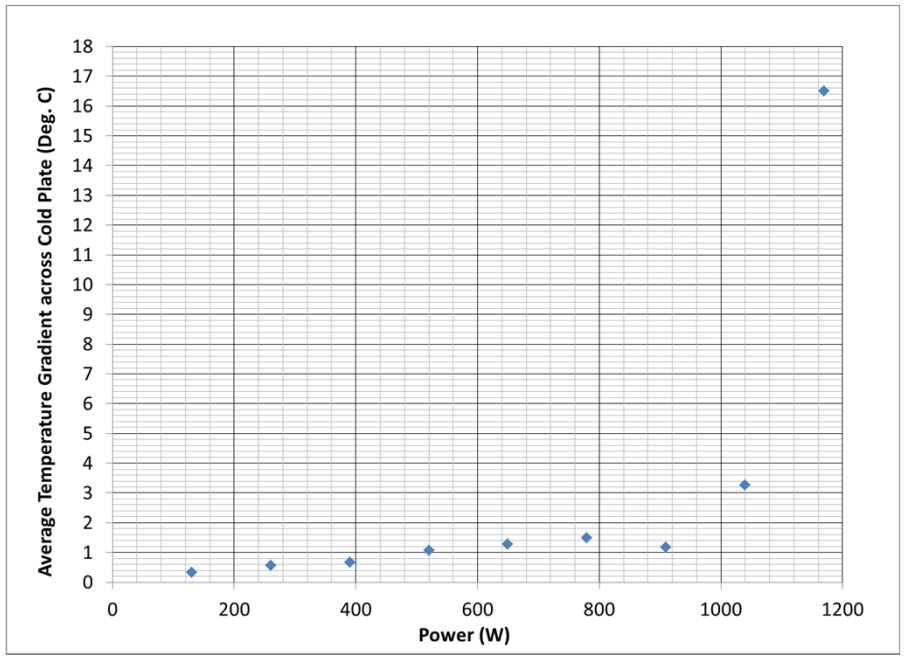
Observations

- No instabilities observed in the cold plates
  - Unique channel design suppressed instabilities associated with changes in thermal load and pressure drop
- Separator distributed phases despite changing heat loads
  - And therefore changing vapor/liquid volumetric flow rates
- Eductors removed vapor and liquid from the MVS at intended rates
- No vapor entered the single-phase pump
- Over 3 kW of heat was rejected across the 3 cold plates

Cold Plate Temperature Data

- Thermal imaging and temperature data showed less than 2 K temperature difference across the cold plate
  - Further optimization could improve this gradient

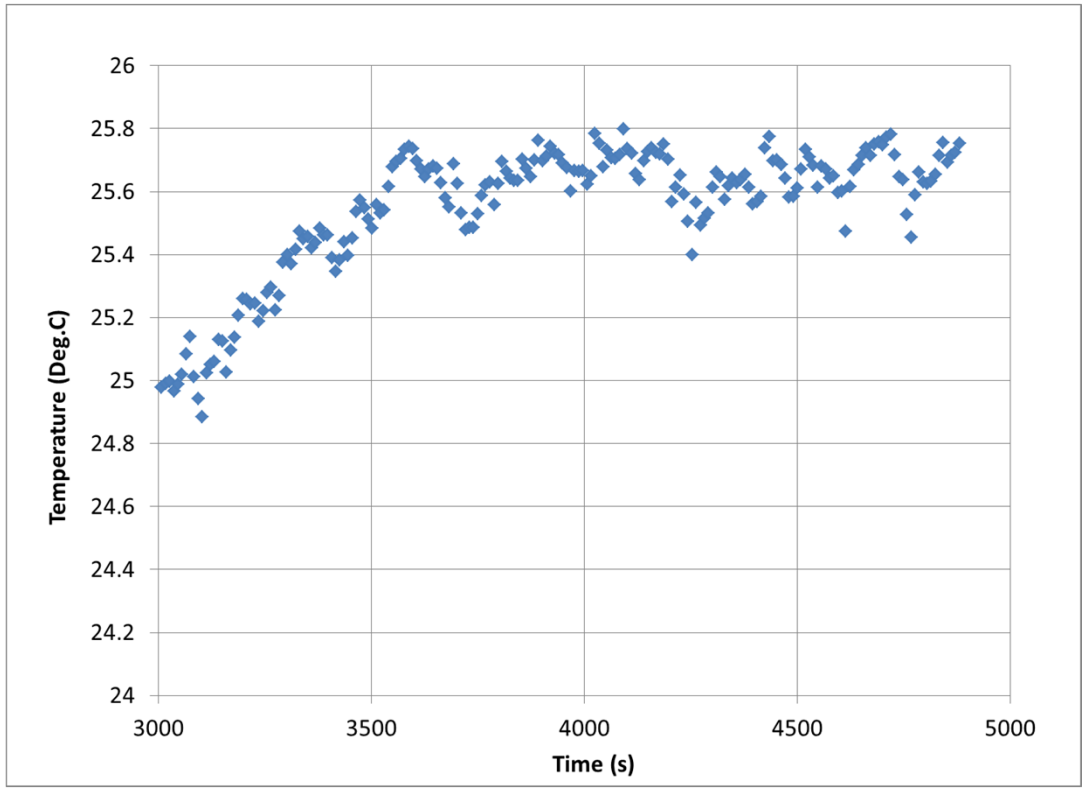




Average Cold Plate Temperature Data

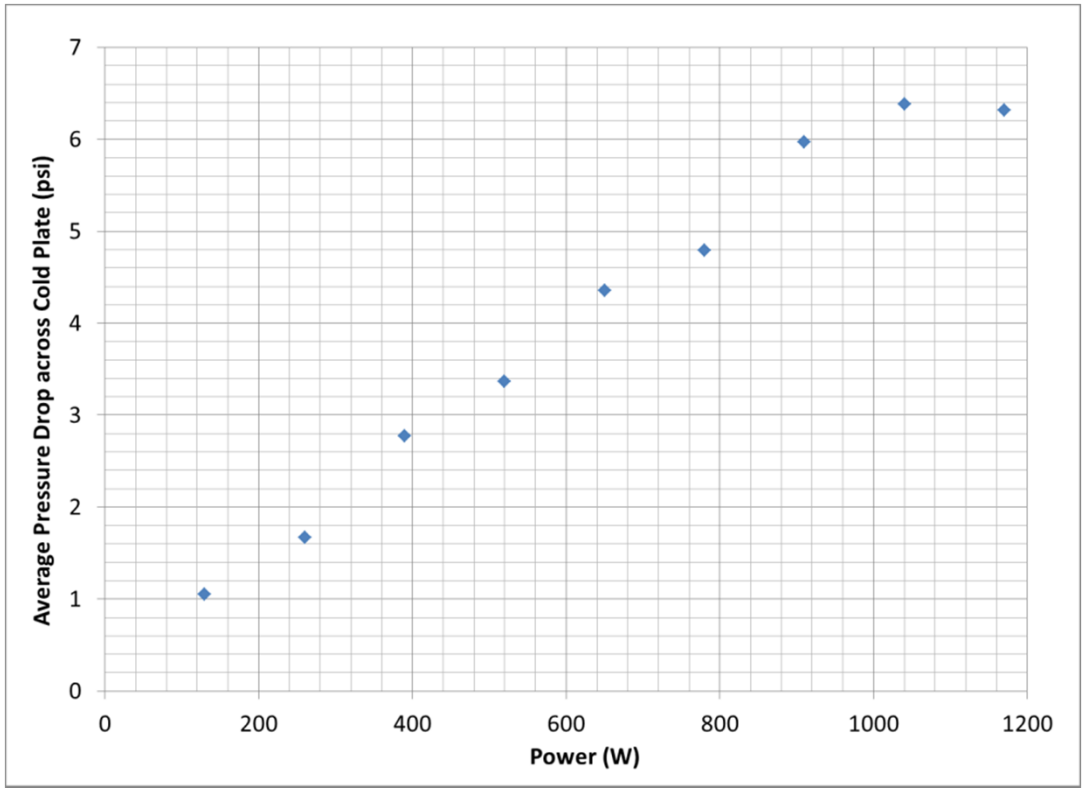
(650 W heat input)

- Heat up period of cold plates after a heat input change of 130 W was about 20 minutes
- 20 minutes of steady state data recorded
- Some variation was seen after steady state
  - Approximately 0.5 K
- Temperature was seen to increase with heat input



Cold Plate Pressure Drop Data

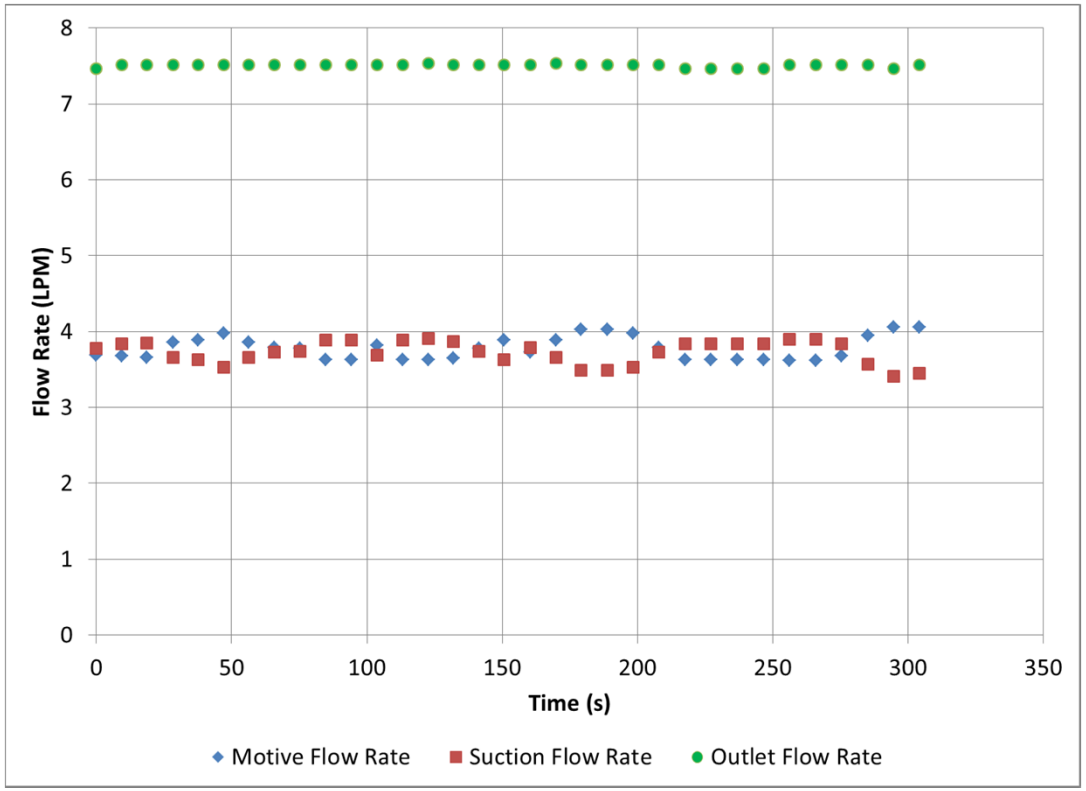
- Pressure drop increased with total heat input
  - 1 psi @ 130 W
  - 6.4 psi @ 1170 W
  - Result of increasing average void fraction
  - After dryout (1170 W), pressure drop is constant



Liquid Outlet Eductor Flow Rate Data

(650 W heat input) for each cold plate

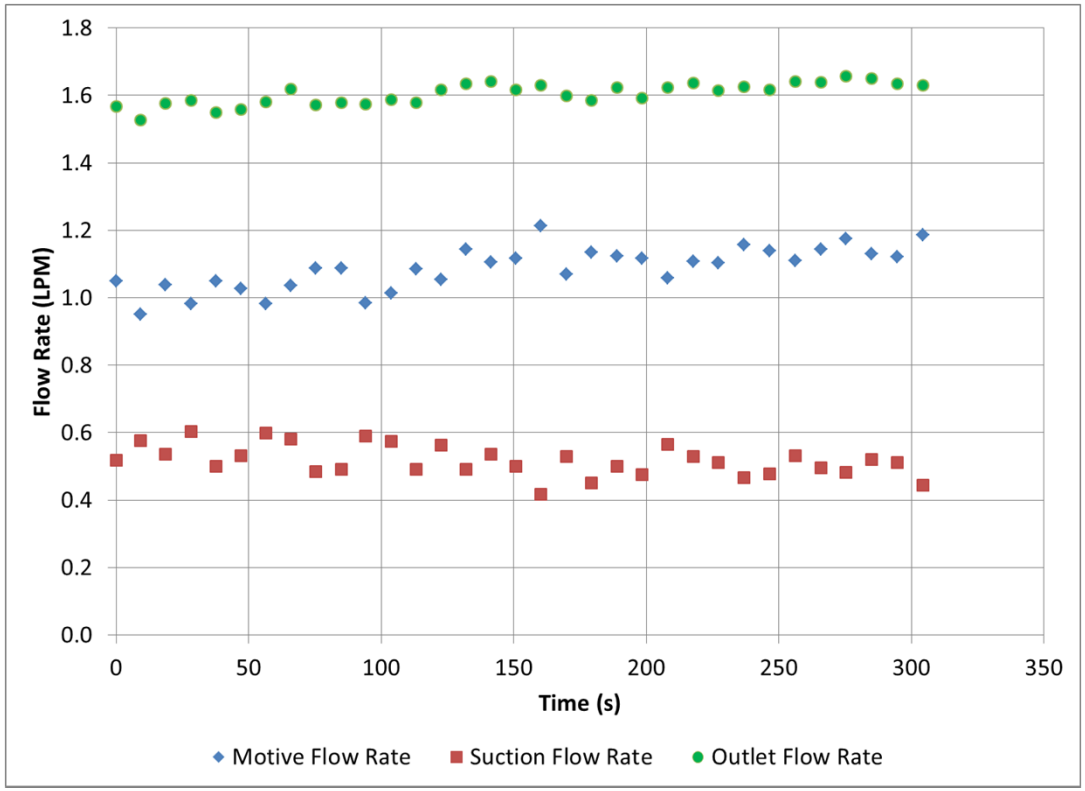
- Motive and suction flow rates are nearly equivalent
  - 1:1 entrainment ratio
- Outlet flow rate is nearly double the motive and suction flow rate
  - Expected as this is a combination of the suction and motive flow rates
  - Discrepancy attributable to measurement error



Vapor Outlet Eductor Flow Rate Data

(650 W heat input) for each cold plate

- Motive flow rate is approximately twice the suction flow rate
  - 2:1 entrainment ratio
  - Result of operating at a lower motive pressure than the liquid outlet eductor
- Outlet flow rate is nearly double the motive and suction flow rate



Conclusion

- Demonstrated several components working together in a two-phase system
  - Single-phase pump
  - Eductors
  - Two-phase cold plates
  - Momentum-driven Vortex Phase Separator
- Stability observed while rejecting over 3.5 kW of heat over 3 cold plates
  - The liquid pump did not cavitate or receive vapor
  - The pump provided motive flow to the eductors
  - The eductors removed liquid and vapor from the separator
  - The separator managed phases with changing heat load (0 to 3.5 kW)
  - Eductors moved vapor and liquid to the condenser and evaporator, respectively
  - Cold plates showed no signs of instability during testing

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